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Life cycle cost of ethanol production from cassava in Thailand

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ABSTRACT

To increase the security of energy supply, lessen dependence on crude oil import and buffer against the impacts of large change in crude oil prices, the Thai government initiated and officially announced the national ethanol fuel program in year 2000. Since then, domestic ethanol demand has grown rapidly. Presently, all commercial ethanol in Thailand is produced from molasses as Thai law prohibits producing it from sugar cane directly. This is likely to limit ethanol supply in the near future. One possible solution is to supply more ethanol from cassava which is widely cultivated in this country. However, its production cost has not yet been known for certain. The objective of this study is to estimate the life cycle cost of ethanol production from cassava and to assess its economic competitiveness with gasoline in the Thai fuel market.

Based on the record of cassava prices during the years 2002–2005, it was found that using it as feedstock would share more than 50% of the ethanol from cassava total production cost. It was also found that a bio-ethanol plant, with a capacity of 150,000 l/day, can produce ethanol from cassava in a range of ex-factory costs from 16.42 to 20.83 baht/l of gasoline equivalent (excluding all taxes), with an average cost of 18.15 baht/l of gasoline equivalent (41, 52 and 45 US cents/l gasoline equivalent respectively, based on 2005 exchange rate). In the same years, the range of 95-octane gasoline prices in Thailand varied from 6.18 baht to 20.86 baht/l, with an average price of 11.50 baht/l (15, 52 and 29 US cents/l respectively, based on 2005 exchange rate) which were much cheaper than the costs of ethanol made from cassava.

Thus, we conclude that under the scenario of low to normal crude oil price, ethanol from cassava is not competitive with gasoline. The gasoline price has to rise consistently above 18.15 baht (45 US cents)/l before ethanol made from cassava can be commercially competitive with gasoline.

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1. Introduction

In Thailand, road transport is the backbone of its transportation systems. Nearly 80% of refined liquid fuels are consumed by vehicles in the road transport sector. At present, Thailand is heavily dependent on imported oil which accounts for more than 90% of all oils consumed annually.

Endowed with suitable climate and fertile soil, Thailand has vast amount of agriculture raw materials for ethanol production. To increase the security of energy supply of the country, the national ethanol fuel program was initiated and officially announced by the Thai government in 2000. However, not until the third oil price shock of 2004 came to pass before public interests in this program caught on widely leading to a dramatic increase in the consumption and production of bio-ethanol in recent years.

Currently, all ethanol produced in Thailand is made from molasses, a by-product of sugar production. Unlike Brazil, no ethanol is directly produced from sugar cane. Under the Sugar cane and Sugar Act of 1984, Thailand has decreed that all sugar cane must only be processed into sugar and its by-products. Due to rapidly increasing ethanol demand for road transport, the availability of molasses for ethanol production is gradually approaching its supply limit. To sustain the national ethanol fuel policy, another candidate agricultural raw material must come on board. Cassava, used mainly as a feedstuff, is available in abundant. Thailand is one of the largest cassava producers in the world exporting around 16 million metric tons annually. Potentially, this surplus of cassava production could be used on a large scale to produce ethanol for domestic consumption, even though this could be at the expense of cassava export.

However, whether ethanol from cassava production cost would be competitive with gasoline price is questionable since this cost has not yet been clearly determined in Thailand. This is indeed vital to the long term sustainability of the Thai Government promoted national ethanol fuel program for gasoline substitution.

The objective of this study is to investigate the economic feasibility of ethanol production from cassava, one of the important cash crops of Thailand, by comparing its production cost to the concurrent gasoline price.

2. The ethanol production process

Both sugar-containing substrates such as sugar cane, sugar beet, Molasses, and starch-containing substrates such as cassava, and corn can be deployed for ethanol production. Although the ethanol production processes from both type of substrates are quite similar, their processing techniques are slightly different in the initial raw materials preparation stage. Sugar-containing substrates, by nature, are fermentation ready without further modification, while the starch-containing ones need an additional step to convert them into fermentable sugar. Subsequent production processes are essentially the same for both types of substrates.

Starch is converted into fermentable sugar via "hydrolysis". Hydrolysis is a chemical reaction between starch and water which breaks down the long chain of starch polymer into fermentable sugar. There are two techniques for hydrolysis: enzymatic and acid hydrolysis. After fermentable sugar is obtained, ethanol can be produced directly by microbial conversion through fermentation by the same strain of yeast used with sugar-based substrate.

Yeast strain used in the sugar fermentation is usually baker's yeast (*Saccharomyces cerevisiae*). It is deployed as a seeding for the fermentation.

Initially, alcohol derived from yeast fermented sugar has a concentration of only about 5–15% by weight [1]. Its concentration is then further increase by separating it from water and other non-fermentable materials. The final concentration of alcohol attained is 95–96% by weight using a distillation method. The concentration at this level is normally called "hydrous alcohol" which can fuel only specially designed internal combustion engine vehicles such as flex fuel cars.

Ethanol commonly uses in Thailand is blended with gasoline at various concentrations of ethanol at 5%, 10%, 20% and 85% by volume forming various grades of gasohol for use in non-specific and specially designed vehicles. In order to make sure that commercial gasohol is compatible with all types of vehicles, the purity of produced ethanol must be an anhydrous ethanol (99.5% alcohol concentration) because ethanol tends to separate from gasoline in the blended gasohol after a period of time unless its purification is higher than 96% by weight.

Consequently, hydrous alcohol is further upgraded by removing the remaining residual water by a "dehydration process". Presently, the molecular sieve method is a commonly used technique in Thailand to separate water out from hydrous ethanol to produce anhydrous alcohol.

It should be remarked here that ethanol production from starch-based crops generally yields four main by-products: stillage, fusel oil, carbon dioxide, and distiller's dried grain (DDG) while ethanol production from sugar-based crops does not produce DDG. Thus, ethanol production from starch-based crops yields one additional by-product more than that of the sugar-based crops.

Stillage is residual beer remaining in the distillation waste after the alcohol has completely been removed from a distillation column. Two distillates are obtained during a distillation process: alcohol and fusel oil. CO_2 is produced by yeast during an anaerobic fermentation process. The amounts of CO_2 produced, by weight, are nearly equal to the amounts of ethanol obtained in the fermentation process.

The ethanol production processes mentioned above are summarized and illustrated in Fig. 1.

3. Estimation of ethanol production cost from cassava in Thailand

Processing costs of ethanol from cassava can be categorized into four groups: feedstock cost, capital cost, operating and maintenance costs, and benefits from by-products.

3.1. Feedstock cost

Feedstock prices can vary by location, seasons, local supply–demand conditions, and transportation. In addition, the local prices are also strongly influenced by world market's prices as Thailand is a large net exporter of cassava. World cassava demand can thus strongly affect local market prices.

3.2. Operating and maintenance costs

The operating and maintenance costs are: labor, energy, electricity, ingredients (e.g. enzymes, yeast, etc.), machine repair

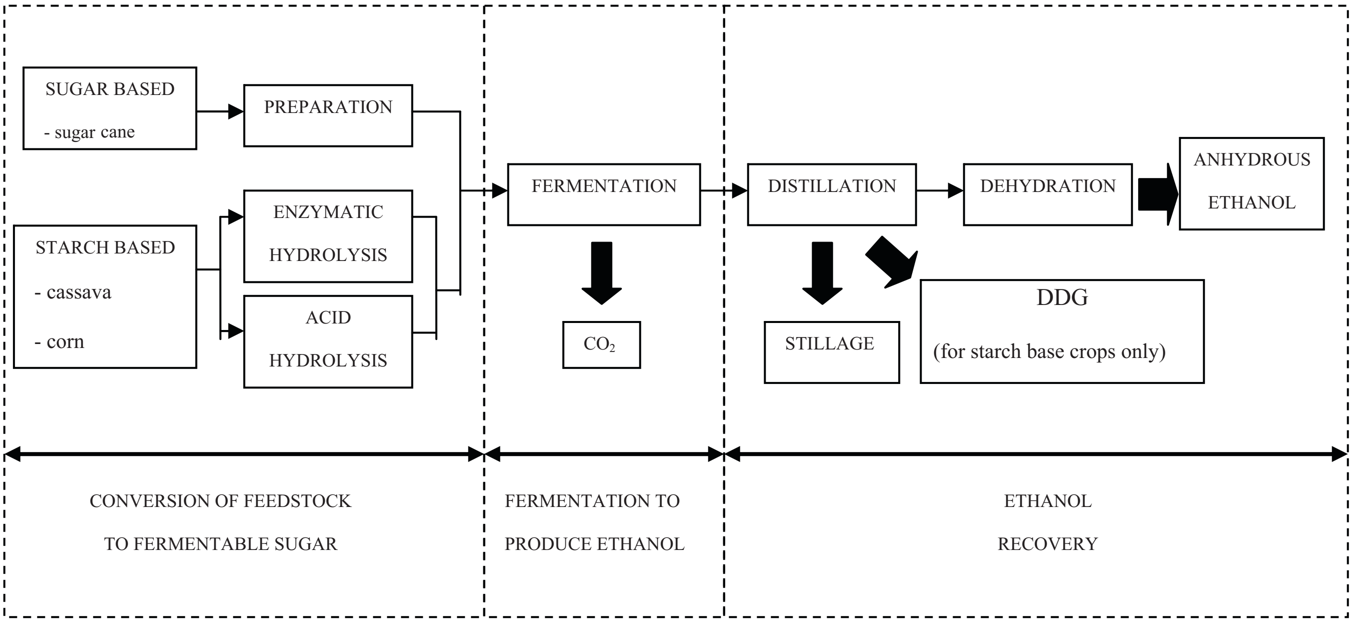

Fig. 1. Anhydrous ethanol production processes from sugar and starch-based feedstock.

and maintenance costs, taxes, insurances, and administrative expenses.

3.3. *Capital costs*

Capital costs comprise all the initial costs of machines and equipments procurements and their installations. It also includes land, site preparation and construction of buildings, infra-structure and other facilities of a processing plant, such as waste treatment units.

3.4. *By-product gains*

As mentioned above, the ethanol production process yields several by-products. For the case of a starch-based ethanol production, the by-products are carbon dioxide, fusel oil, stillage and DDG. These by-products can generate additional incomes which can significantly offset the production cost of ethanol provided that they are effectively recovered.

Thus, the unit cost of ethanol production can be expressed by the equation

$$C_{Et} = C_F + C_{O\&M} + C_I - C_B \quad (1)$$

where C_{Et} is the ethanol production cost (USD/l); C_F is cassava feedstock cost (USD/l); $C_{O\&M}$ is operating and maintenance cost (USD/l); C_I is investment cost (USD/l); and C_B is by-product gains (USD/l).

3.5. *Assumptions for the estimation of ethanol production cost in this study*

In this study, fresh cassava is assumed to be the feedstock for ethanol production by an ethanol plant with a capacity of 150,000 l/day to produce anhydrous fuel grade alcohol. The plant is assumed to operate 330 days/year. The project life is assumed to be 20 years, and the interest rate of this investment is 6%/annum. Prices in the year 2005 were chosen as the base year for the analysis in this study. Financial values in other years were converted to the reference year by using the annual Thai Consumer Price Index (CPI).

The yield of ethanol from cassava was calculated based on figures obtained from Thailand Institute of Scientific and Technological Research (TISTR)'s pilot plant. Other raw materials needed for processing such as enzymes, yeasts, water and chemicals were also based on the data given by TISTR [2]. Table 1 shows the yield of ethanol from cassava and other general technical assumptions used in this study.

4. Estimation of cassava feedstock costs

Past records of cassava prices during years 2002–2005 [3] were referenced. All prices were adjusted to prices of the base year 2005. The average price of cassava during these years was found to be 1096 baht/metric ton or 27.40 USD/metric ton (1 USD = 40 baht, an average exchange rate in 2005). With the yield of ethanol from cassava at 160 l/ton as shown in Table 1, the cost of cassava for 1 l of ethanol produced can be estimated. It was found that the feedstock costs of cassava for ethanol production varied with fresh cassava prices from 5.75 to 8.56 baht/l of ethanol, or equivalent to 14.4 cents to 21.4 cents/l. The maximum, minimum, and average of fresh cassava prices are given in Table 2.

The raw material cost is the single largest expense item of the ethanol production processes. Like other agriculture cash crops, the prices of cassava feedstock are, in general, highly volatile. More details will be given in Section 10.

5. Estimation of capital investment cost (C_I)

Two entities of capital investment are involved in the development of an ethanol production plant. The first one is the direct costs of the first investment such as land, the main plant and office

Table 1
Feedstock yield and technical assumption in this study.

Feedstock	Cassava
Ethanol yield (l/ton)	160
Plant's feedstock input rates (ton/day)	940
Plant's capacity (l/day)	150,000
Annual production (million l)	49.5
Operation days (days)	330
Project life (years)	20
Interest rate	6%/annum
Year for cost basis	2005

Table 2
The maximum, minimum, and average costs of feedstock in baht/ton and baht/l of ethanol during years 2002–2005.

Feedstock	Maximum		Minimum		Average	
	Baht/$ton_{feedstock}$	Baht/$l_{ethanol}$	Baht/$ton_{feedstock}$	Baht/$l_{ethanol}$	Baht/$ton_{feedstock}$	Baht/$l_{ethanol}$
Cassava	1370	8.56	920	5.75	1096	6.85

buildings, warehouses, laboratories, instrumentation and piping works, etc. The second one is the indirect costs of the first investment such as engineering consulting fees and other contingency allowances.

In this study, we adopted two techniques to estimate the capital investment costs. Whenever possible, costs of machines and equipments were estimated directly from manufacturers' price quotation, particularly those for special processing equipments used only in this industry, e.g. molecular sieve, etc. The second technique is to estimate costs of machines and equipments based on their historical prices adjusted to the present prices in the reference year. The second technique was adopted only when the first technique was unavailable. We found that the total equipment costs were about 413 million baht, or 10.325 million USD (values in year 2005).

The indirect costs were estimated from the certain average percentages of the total direct cost of the plant, as recommended by Garrett [4]. In this study, the total capital investment costs were found to be 1208 million baht, or equivalent to 30.2 million USD, for a project life of 20 years, with a capacity of ethanol production of 150,000 l/day. All major items of the investment costs are summarized and shown in Fig. 2.

A breakdown of the total capital investment cost of the ethanol production as a unit cost (the capital cost per liter of the ethanol) was then calculated by amortization, recovered over the life time of the plant. This can be obtained by a common annualized capital cost equation:

$$A = P\left[\frac{i\,(1+i)^n}{(1+i)^n - 1}\right] \tag{2}$$

where A is the annual payments (baht or USD/year); P is the present worth of the first investment cost (baht or USD); i is the annual interest rate; and n is the project life in years.

The annualized capital investment cost is then divided by annual amounts of ethanol produced to obtain the capital cost per liter of the ethanol. In this study, the capital investment cost per liter of the ethanol was found to be 2.13 baht or 5.33 cents, for the annual interest rate of 6% and the project life of 20 years.

6. Operating cost ($C_{O\&M}$)

In this study, all operating expenses including all consumable materials for production such as operations of utilities, labor, repair and maintenance, administration, etc., were estimated and adjusted to the prices in the base year 2005. The administration expenses were assumed as a fixed percentage of the total labor cost. For the costs of operating and maintenance, and the plant's insurance, each item could also be assumed as a fixed percentage of the annualized capital cost [5]. The operating cost per liter of the ethanol can be calculated by dividing the total annual operating costs by the annual capacity of the ethanol production. The operating cost per unit of the ethanol from fresh cassava was found to be 3.67 baht/l or 9.175 cents (see details in Table A1 in Appendix A).

7. Gains of by-products (C_B)

As mentioned previously, certain by-products of the ethanol production are generated from the production processes and wastes. They are considered to be of benefit to investors and can offset the burden of production costs. In this study, carbon dioxide and fusel oil were assumed to be wastes and no values. On the other hand, DDG is a by-product in a form of cassava cake that can be sold for animal feeds. In addition, biogas from waste water treatment can be used as fuel for heating. Both are considered to be beneficial by-products. The total value of the by-product gains from cassava is 1.09 baht/l, or equivalent to 0.273 cents/l.

The beneficial by-products mentioned above are supposed to generate additional incomes (or gains) to ethanol producers. The details of the calculated results are shown in item V of Table A1 in Appendix A. The benefits from the by-products were subtracted

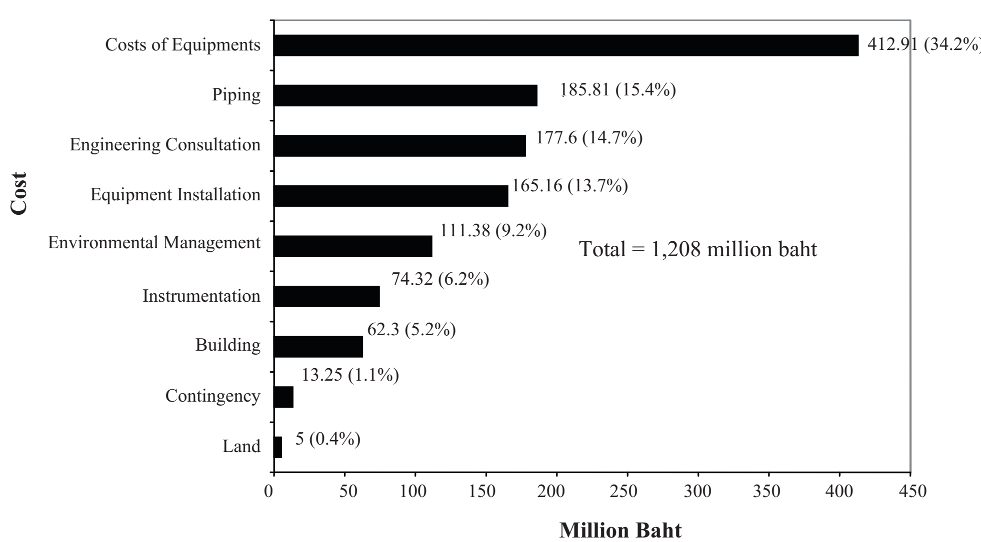

Fig. 2. The investment cost of an ethanol plant, with a capacity of 150,000 l/day in Thailand.

Table 3
Unit cost structures of ethanol production from cassava.

Feedstock	Cassava		
	Maximum	Minimum	Average
Feedstock cost (baht/l)	8.56	5.75	6.85
Net operating cost (baht/l)		2.58	
Investment cost (baht/l)		2.13	
Total ethanol cost per liter (baht/l)	13.27	10.46	11.56
Total ethanol cost per liter of gasoline equivalent (baht/l)	20.83	16.42	18.15

from the overall operating costs. Hence, the final net operating cost of the ethanol obtained from cassava was found to be 2.58 baht/l, or 0.645 cents/l.

8. The total unit cost of the ethanol production from cassava

Table 3 and Fig. 3 show the cost structure of a unit cost of ethanol production from fresh cassava roots. It is obvious that the raw material cost accounts for the highest share of the total unit cost of the ethanol production. Based on past price records during years 2002–2005, the cassava feedstock cost accounted for about 59% of the total cost, while the net operating cost shared only 22% and the capital cost took another 18% of the total cost.

Since the calorific energy content per liter of ethanol is lower than that of gasoline, 1 l of ethanol contains only 20.5 MJ while a liter of gasoline contains 32.1 MJ, it is necessary for energy equivalency comparison to adjust for an equivalent ethanol volume that can release the same amount of calorific energy as that of 1 l of gasoline. This can be done simply by multiplying a factor of 1.57 (32.1 MJ divided by 20.5 MJ) into the unit cost of ethanol to derive the volume of ethanol that can deliver the same amount of calorific energy as 1 l of gasoline.

The prices of calorific energy equivalent ethanol volume from cassava to that of a liter of gasoline are also given in Table 3.

9. Analysis of competitiveness between bio-ethanol from cassava and gasoline

As shown in Fig. 3, the largest portion of the ethanol production costs is the feedstock cost. Since this cost is highly volatile, for ease of analysis, we calculated a unit cost of ethanol produced from cassava as a function of the variable prices of cassava feedstock. Finally, a range of variable unit costs of ethanol can be determined as follows:

Because the operating cost and investment cost are relatively constant, we can assume them to be fixed values while the feedstock cost is treated as a variable term. From Table 3, the operating and investment cost of cassava are 7.39 (=4.71 × 1.57) baht/l of gasoline equivalent (or 18.5 US cents).

From Table 1, the ethanol yield of cassava is 160 l/ton. If the price of cassava is X baht/ton, then we can formulate the unit cost of ethanol production from cassava in term of baht per liter of gasoline equivalent, $Y_{eq,}$ as follows:

$$\begin{aligned} Y_{eq} &= 7.39 + \frac{1.57}{160}X \\ &= 7.39 + (9.81\mathrm{E}-03)X \end{aligned} \qquad (3)$$

By comparing the past price records of 95-octane gasoline (at the ex-refinery plants before taxes) with the estimated ethanol production prices from cassava during the same period of years 2002–2005 as shown in Fig. 4, we can assess the competitiveness of ethanol produced from cassava to that of 95-octane gasoline. The details of assessment will be discussed in the next section.

10. Discussion and conclusion

It should be pointed out that the data on the price movements of cassava and gasoline used for the analysis in this study are from the years 2002–2005, a relatively short period of only 4 years. Hence, the unit costs of ethanol from cassava presented here are valid only for this specific time interval. Any generalization of the conclusion of this study to other time interval should be done with great caution because both the price of cassava and gasoline could and are expected to deviate significantly from the prices in the

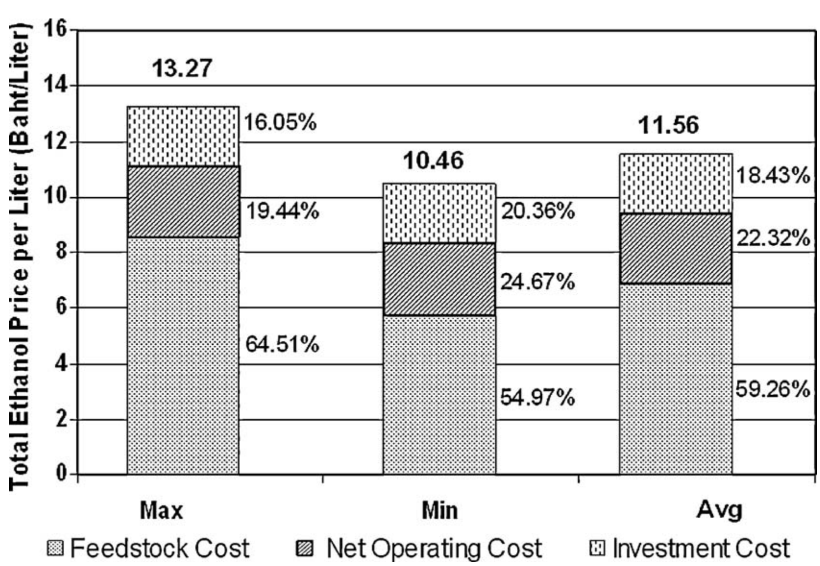

Fig. 3. Cost structures of the ethanol production from fresh cassava roots.

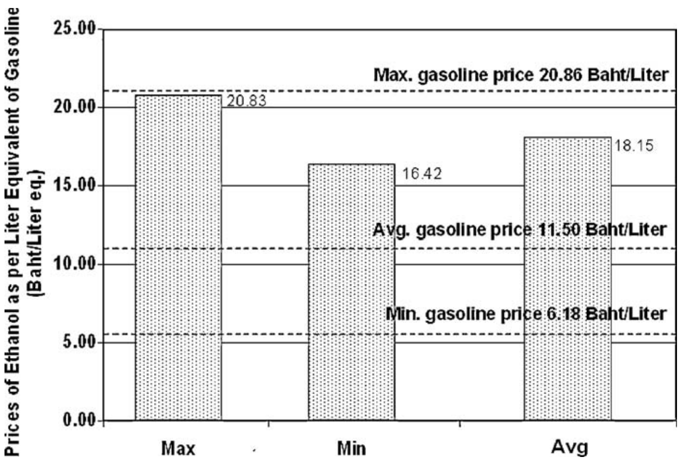

Fig. 4. Comparisons between the maximum, minimum and average prices of the ethanol as per liter of gasoline equivalent and 95-octane gasoline prices (at ex-refinery price, excluding all taxes), during years 2002–2005.

years 2002–2005, not necessarily in the same direction, resulting in varying relative prices of ethanol from cassava and gasoline which could cause one to reach a different conclusion. Nevertheless, a framework and means for the analysis has been laid out through formulated equations allowing one to adjust both fixed and variable parameters when attempting to analyze with a significantly different data set belonging to a different time interval. This study has uncovered some interesting aspects concerning the characteristic of the production cost structure for a 150,000 l/day ethanol plant in that the preponderant parameter affecting the unit cost of ethanol from cassava is the feedstock itself and the specific conditions under which ethanol form cassava could compete with gasoline in Thailand could also be delineated.

Since 95-octane gasoline, a type of refined petroleum products derived from imported crude oil, is currently targeted by the Thai Government for complete phasing out to be replaced by indigenous bio-ethanol blended gasoline. Therefore, the price of 95-octane gasoline was chosen for comparative competitiveness with the cost of ethanol from cassava during the time period of this study. As shown in Fig. 4, by comparing the concurrent prices of both during the years 2002–2005, we can discuss and draw the following conclusions:

(a) Fig. 3 clearly shows that the price of cassava feedstock is the preponderant factor for the competitiveness of bio-ethanol from cassava since it always accounts for more than half of the total ethanol production cost. Hence, the competitiveness of the ethanol produced from cassava highly depends on the variation of the feedstock relative to gasoline prices. During the years 2002–2005, the price of cassava, "X" in Eq. (3), varied from 920 to 1370 baht/ton with the average price of 1096 baht/ton resulted in the shares of the feedstock costs per liter of ethanol from cassava varying in a range of 55–65% of the total unit cost of ethanol.

(b) As shown in Fig. 4, the average cost of ethanol from cassava was 18.15 baht (45 cents)/l of gasoline equivalent which was much higher than the concurrent average price of 95-octane gasoline. Even when the ethanol from cassava production cost was at the minimum (i.e. the lowest price of cassava feedstock), its production cost was still significantly higher than

Table A1
Net operating costs (including gains from by-products) of cassava.

Item	kg/day	Unit price (baht/kg)	Cassava	
			Annual expense (baht/year)	Unit cost (baht/l)
I. Raw material preparation process				
Water	398,400	0.021	6,849,661	0.14
Ammonium sulphate	0	25	7,194,000	0.15
Potassium sulphate	0	90	5,167,800	0.10
Sulfuric acid	0	35	7,830,900	0.16
Alpha-amylase	0	200	25,542,000	0.52
Gluco-amylase	0	250	31,927,500	0.65
Subtotal			84,511,861	1.71
II. Fermentation process				
Water	199,448	0.021	1,382,175	0.03
Antifoam	28	200	1,848,000	0.04
Molasses	56,090	1.5	27,764,550	0.56
Formalin	28	43	397,320	0.01
Subtotal			31,392,045	0.63
III. Utilities				
Steam	360,000	0.42	59,875,200	1.21
Electricity	1125 kW	2	742,500	0.02
Subtotal			60,617,700	1.23
IV. Labor, supplies and overhead costs of direct labors	Daily wage (baht/day)	Operator/shift (crews/shift)		
Operators	200	5	990,000	0.02
Maintenances	200	2	396,000	0.01
Administration salaries	40% of O & M labor		554,400	0.01
Operating supplies	0.75% of annual capital		567,965	0.01
Maintenance supplies	1% of annual capital		757,287	0.02
General and administrative	60% of total labor		1,164,240	0.02
Insurance	0.75% of annual capital		567,965	0.01
Subtotal			4,997,857	0.10
Total			170,352,263	3.67
V. By-product credits				
CO_2	126,343	0	0	0
Refuse	0	−0.1	−32,150,580	−0.65
Net biogas profit			−21,742,380	−0.44
Total			−53,892,960	−1.09
Net operating cost				2.58

the concurrent minimum and average price of the gasoline by 10.24 baht (26 cents) and 4.92 baht (12 cents)/l respectively. Moreover, from Eq. (3), it clearly shows that even the cassava feedstock has no cost (i.e. $X=0$), yet the ethanol cost is still higher than the minimum price of gasoline. This implies that when the crude oil price on the world market is in a slump, ethanol from cassava just is not competitive with gasoline. And even under the normal crude oil price situation, ethanol from cassava is still unlikely to be able to complete with the gasoline.

(c) However, it should be noted here that since 2005, gasoline prices in Thailand have been in an upward trend paralleling the climb in crude oil price on the world market which peaked in mid 2008. Under this scenario, ethanol from cassava could become competitive with gasoline if the price differentials are large enough as follows:

If the gasoline price is greater than the concurrent average production cost of ethanol from cassava, then ethanol will be in a better position to be competitive. During the years 2002–2005, we determined that the average production cost of ethanol from cassava was 18.15 baht (45 cents)/l. The corresponding imported crude oil price during the same period for the price of 95-octane gasoline at 18.15 baht/l would be around 50 USD per barrel (or equal to 78 USD per barrel in 2010 dollar).

The most favorable condition for cassava competitiveness would be the situation when the lowest cassava price coincides with the highest gasoline price. Under this hypothetically favorable and unlikely situation, had it occurred during the years 2002–2005, the production cost of the ethanol from cassava would had been lower than the price of the gasoline by 4.44 baht (11 cents)/l of gasoline equivalent. Ethanol producers could have had around 25% competitive advantage of ethanol production cost from cassava.

Consequently, we can draw the conclusion from this study that ethanol produced from cassava is still unlikely to be able to compete with gasoline in the energy market in Thailand in the near term, and we expect that this conclusion, having been drawn from the specific case of Thailand, is likely to be applicable elsewhere in the world since Thailand is one of the largest world cassava producers whose cassava cost is very highly competitive on the world market.

Nevertheless, under the scenario when crude oil price is extremely high, ethanol from cassava could possibly become competitive with gasoline. From our point of view, we believe that cassava still has the potential to be competitive with gasoline in the not too distant future given the fact that the world is likely to be close to; or even has gone beyond the peak oil supply. Future scarcity of crude oil supply could sharply boost its price to the level where gasoline price is significantly higher than ethanol from cassava. Ethanol from cassava competitiveness could also be achieved sooner if the yield of cassava cultivation could be improved significantly to reduce the feedstock cost.

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Appendix A.

Table A1.

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